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SENSITIVE ELEMENTS OF BASIC DIRECTION «EAST – WEST» WITH OSCILLATING MASS FOR A GRAVITATIONAL-INERTIAL COMPASS

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Manufacturing of devices for tool orientation based on action of Koriolis force on mass which oscillates along the vertical of a place is considered. Possibility of technical realization of sensitive elements of a gravitational-inertial compass on the basis of the orientation mechanism of alive organisms is shown.

Orientation of persons, mobile and motionless objects in ground and underground conditions, on the water surface and in underwater remains vital necessity of an industrial society. There are new, earlier not met before situations (zones of powerful magnetic and electromagnetic fields, the centers of natural and technogenous catastrophes, a long presence of mobile objects in ocean depths etc.), in which existing means of tool orientation: magnetic, induction, gyroscopic and radio compasses can not ensure a trustworthy information about basic directions in full measure [1]. Creation of independent navigating devices and their sensitive elements capable to work reliable in these situations, becomes urgent need

Biological systems of orientation surpass the majority of technical systems in accuracy of end results, on diminutiveness and reliability. It more often forces developers of precision technical navigation systems to pay attention to the problem of studying of mechanisms of space orientation of migrating birds.

As the result of the researches carried out by G.A. Shvetsov [2], the concept of the biological gravitational-inertial compass has bee formed. It is understood as the set of sensitive elements, capable to catch the portable acceleration arising owing to vertical reciprocating moving of the centre of mass of biological object, daily rotation of the Earth and, with the help of the central nervous system to reveal with high accuracy the East – West direction. Such navigating device is capable to function reliably in various weather conditions at influence of magnetic and electromagnetic noises, in an environment of ferromagnetic materials, in radioopaque environments.

Up to middle of 90[th] years of the last century practical development of such sensitive elements on the basis of biological systems of orientation were absent.

Creative group into which authors entered, developed a number of sensitive elements of mechanical and liquid types (see the table), protected by the patents of Russian Federations [3–6], and carried out research of their dynamic and precision characteristics.

In a considered sensitive element of the basic East – West direction in acting physical size is the Koriolis acceleration. It appears as an objective reality at movement of a body in circumterraneous space and characterizes change of a relative velocity vector $\upsilon_{\text{отн}}$ progress of a body in weight m in translation rotary movement of the Earth Ω_3. Appearing acceleration causes the Koriolis force F_K which is always directed to the side opposite to acceleration. The way of orientation consists in definition of size and direction of the Koriolis force (or its manifestations), working on an inertial body moving in relation to the Earth.

The works for creation of technical analogue of a biological gravitational-inertial compass have begun from research of the sensitive element scheme with a motionless point of an elastic suspension. Such type of a sensitive element is development of the device proposed by G.A. Shvetsov [2] for demonstration of the orientation discovered by him. The force action scheme in the sensitive element of similar type is given on Fig. 1.

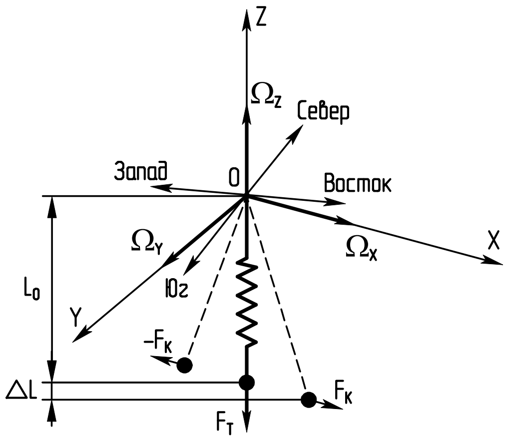


Fig. 1. *The force action scheme in the sensitive element with a motionless point of an elastic suspension*

In a general view the system of the equations describing movement of an inertial body, has form:

$$\left.\begin{aligned}
&\ddot{x}+2\Omega_y\dot{z}-2\Omega_z\dot{y}+\frac{k}{m}\left(1-\frac{L_0}{L_0+\Delta L}\right)x=\frac{F_{\text{K}x}}{m}+F_x\\
&\ddot{y}-2\Omega_x\dot{z}+2\Omega_z\dot{x}+\frac{k}{m}\left(1-\frac{L_0}{L_0+\Delta L}\right)y=\frac{F_{\text{K}y}}{m}+F_y\\
&\ddot{z}+2\Omega_x\dot{y}-2\Omega_y\dot{y}+\frac{k}{m}\left(1-\frac{L_0}{L_0+\Delta L}\right)z=g+\frac{F_{\text{K}z}}{m}+F_z
\end{aligned}\right\}, \quad (1)$$

where: $F_{\text{K}x}$, $F_{\text{K}y}$, $F_{\text{K}z}$ – are projections of the Koriolis force on the corresponding axes; Ω_x, Ω_y, Ω_z – are projections of the vector of rotation of system of coordinates on the corresponding axes; F_x, F_y, F_z – are projections of external force on the corresponding axes; k – is rigidity of an elastic element; m – is mass of an inertial body; g – is acceleration of free falling; L_0, ΔL – are initial length and relative lengthening of an elastic suspension; x, y, z – are coordinates.

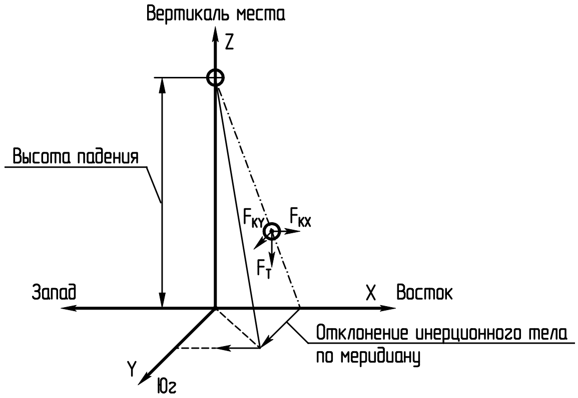


Fig. 2. *The force action scheme on a free-falling inertial body*

Analytical research of dynamics on the basis of system of the equations (1) has shown, that in the orientation device it is necessary to provide parametrical resonant oscillations. In this case it is possible to create the sensitive element allowing reliably and with required accuracy to define a line of the first vertical. At the same time mathematical simulation has revealed lacks of the sensitive element of the given type, in particular, an error of definition of a direction increasing in time [7].

To eliminate the specified lacks research of a sensitive element on the basis of a free-falling inertial body was carried out. Advantage of the orientation device of such type is the opportunity to minimize an error of revealing of the basic East – West direction since the inertial body at its free falling is not affected by suspension elements. The scheme of force action on a free-falling inertial body is shown on Fig. 2.

The differential equation of movement along a vertical of the place of a freely falling inertial body in projections on axes X, Y, Z has form:

$$\left.\begin{aligned} -m\frac{d\upsilon_z}{dt} &= -mg + F_{cz} \\ m\frac{d\upsilon_x}{dt} &= -\sum_{i=1}^{n}\vec{F}_{Ki} - F_{cx} \\ m\frac{d\upsilon_y}{dt} &= -\sum_{i=1}^{n}\vec{F}_{Ki} - F_{cy} \end{aligned}\right\}, \qquad (2)$$

where: F_{cx}, F_{cy}, F_{cz} – are forces of aerodynamic resistance to free falling of an inertial body on the appropriate axes of coordinates; υ_x, υ_y, υ_z – are projections of linear velocity of an inertial body; F_{Ki} – is a vector of the Koriolis force at the certain moment of time.

The research of dynamics which has been carried out on the basis of system of the equations (2), definition of conditions and detachment areas of an inertial body from a vibrating platform, optimization of dynamic characteristics have shown ability to create the orientation device and achievement of acceptable accuracy parameters at revealing of the first vertical line. On the basis of these researches prototyping of the sensitive element, fig. 3 has been carried out. The real characteristics received at test of the model, have coincided with theoretical one with an accuracy of 20 %.

Two optical ways of reading of information on the vector of movement of the inertial body under action of the Koriolis force are developed and realized: two-channel and matrix. They allow to measure micromovings of the inertial body in the real time mode in a horizontal plane in the angle range being equal 2π, not rendering force influence on its dynamics.

Research of aerodynamics, the geometrical sizes and the falling inertial body form has revealed that the best result, as though it seemed at first sight not logical, is possible to reach at the organization of falling of an inertial body in resisting medium. Therefore during creation of an able-boded design the sensitive elements liquid type have been developed and their dynamics has been investigated. The forces working on the inertial body, being in a liquid, are shown on Fig. 4.

The equations of dynamics of a half-submerged inertial body has form:

$$\left.\begin{aligned} \frac{d^2x}{dt^2} &= F_K - F_{\Gamma C}(\upsilon_x) - \sigma l_{\Gamma P}\sin\theta \\ \frac{d^2y}{dt^2} &= 0 \\ \frac{d^2z}{dt^2} &= mg - F_A - F_{\Gamma C}(\upsilon_z) \end{aligned}\right\}, \qquad (3)$$

Where: F_A – is the Archimedes force; $F_{\Gamma C}$ – is force of hydrodynamic resistance; σ – is a superficial tension factor; $l_{\Gamma P}$ – is length of the border of a superficial layer of a liquid; θ – is an angle describing value of the superficial tension.

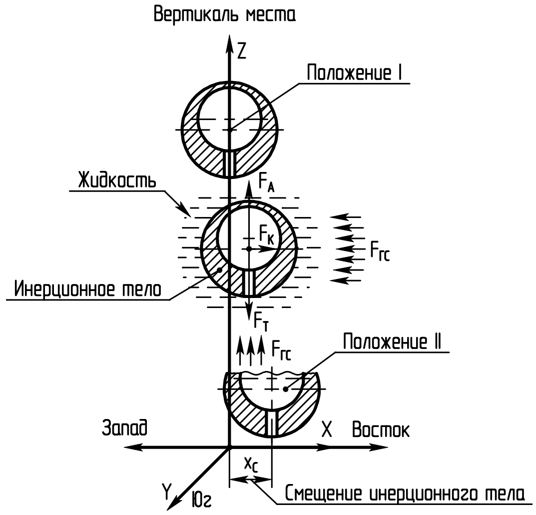
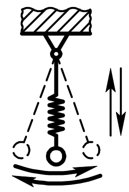
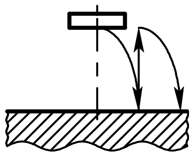
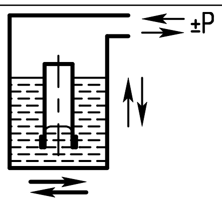
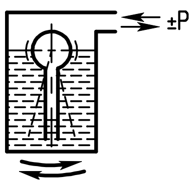


Fig. 4. *The forces acting on an inertial body, completely submerged in a liquid*

The analysis of the solution of the system of the equations (3) has revealed shortcomings of the sensitive float element scheme [8]. The basic from them is absence of restoring force and, hence, making reciprocating mo-

Table. *Types of the investigated sensitive elements*

The name of Sensitive Element	Kinematical scheme	Principle of action of the Sensitive Element	The RF Patents
Mechanical sensitive elements			
A pendulum with an elastic element and a motionless point of suspension		The inertial body on elastic suspension makes oscillations along a vertical of a place, deviating on an angle from the suspension point in the East - West direction under action of Koriolis force.	№ 2174217
With a free falling inertial body		An inertial body in free falling under action of the Koriolis force deviates to the East from initial point of falling.	№ 2217698
Liquid sensitive elements			
A float one with a half-submerged inertial body		An inertial body, half-submerged in a liquid, rises and submerged at change of pressure above a liquid, making oscillations in the East - West direction under action of Koriolis force.	№ 2183820
A ballistic one with a half-submerged inertial body		An inertial body, half-submerged in a liquid and kept along a vertical of a place by forces of a surface tension of the liquid, deviates on the angle in the East - West direction due to energy saved up before (during movement of the liquid on a tube at change of pressure above a liquid).	№ 2234062

tion along the vertical of a place, the body will not come back in a starting position (on the initial vertical of a place), and will be displaced under action of Koriolis force and a different sort of casual oscillations of a liquid.

The sensitive element constructed by the ballistic circuit, Fig. 5, became the further development of the sensitive float element for the orientation device, It differs that in it the inertial body with positive floatability is constantly kept in the certain position by superficial tension forces of the liquid which moves only in a tube which section is small in relation to an inertial body.

Definition of the basic direction occurs as a result of fast rise of the liquid on a tube from level I up to a level II at increase of pressure over the liquid ($P_0+\Delta P$). At rise of a liquid it will be acted by the Koriolis force F_K, directed to the West. Pulse influence of force on a mobile part will be shown in ballistic effect: the mobile part of an inertial body practically remains in rest during action of the pulse F_K and begins its movement only after the pulse has ended. It will cause turn of the body 1 on an angle φ in the western direction. Value of this deviation will be defined by expression:

$$\varphi = \frac{\pi d^2 (H_2 - H_1)\rho \Omega_3 l_0}{2C_ж} \cdot \sqrt{\frac{P_2 - P_1}{2\rho}} \cdot \frac{e^{-\beta\omega_0 t}}{\sqrt{1-\beta^2}} \times \times \sin(\omega_0 t\sqrt{1-\beta^2})\cos\lambda, \qquad (4)$$

Where: β – is the factor determining dynamic characteristics of «a liquid – an inertial body» system; ρ – is the liquid density; d – is the tube diameter; H_1 and H_2 – are an initial and final level of the liquid in the tube at different pressure; l_0 – are distances from the centre of mass up to the geometrical centre of an inertial body; $C_ж$ – is factor of dynamism; ω_0 – is frequency of own fluctuations of the system; P_1 and P_2 – initial and final pressure of gas over the liquid.

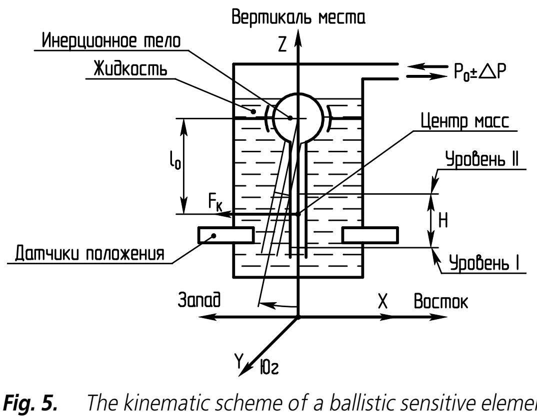


Fig. 5. *The kinematic scheme of a ballistic sensitive element*

Simulation on the basis of expression (4) was carried out by means of program Matcad 8.0 for various values of variables. The most typical mode (for values

β=0,1; ρ=790 kg/m^3; $C_ж$=0,52·10^{-5} kg·m/s) is presented on Fig. 6. Process of attenuation of the inertial body fluctuations after initial ballistic throwing for other values of variables has the same character, differing with attenuation time (no more than 30 s).

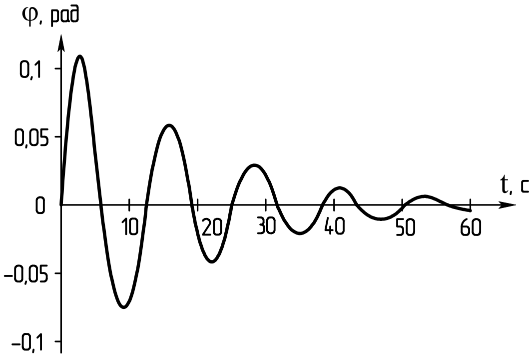


Fig. 6. *Process of attenuation of the inertial body fluctuations*

Simulation has shown that, the value of «ballistic throwing» is great enough and under certain conditions can reach 6°, that is more than enough for its reliable fixing by system for read-out of an information.

The carried out theoretical researches of dynamics of sensitive elements of the basic West-East direction with a mass oscillating along the vertical of a place and their physical and mathematical simulation yielded the following results:

1. The sensitive element for definition of an azimuth on the basis of the biological mechanism of wave gravitational-inertial orientation discovered by G.A. Shvetsov having no prototype in the navigation field, is created.
2. Optical two-coordinate (channel) and direct measurement (matrix) ways of read-out of information on a vector of movement of an inertial body under action of Koriolis force are developed and realized.
3. It is necessary to consider that the sensitive element on the basis of a free-falling inertial body is the most perspective from the point of view of minimization of drift (due to the individual act of measurement) and on velocity from the investigated types of sensitive elements for orientation devices.

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